Aerosol properties in a cloudy world

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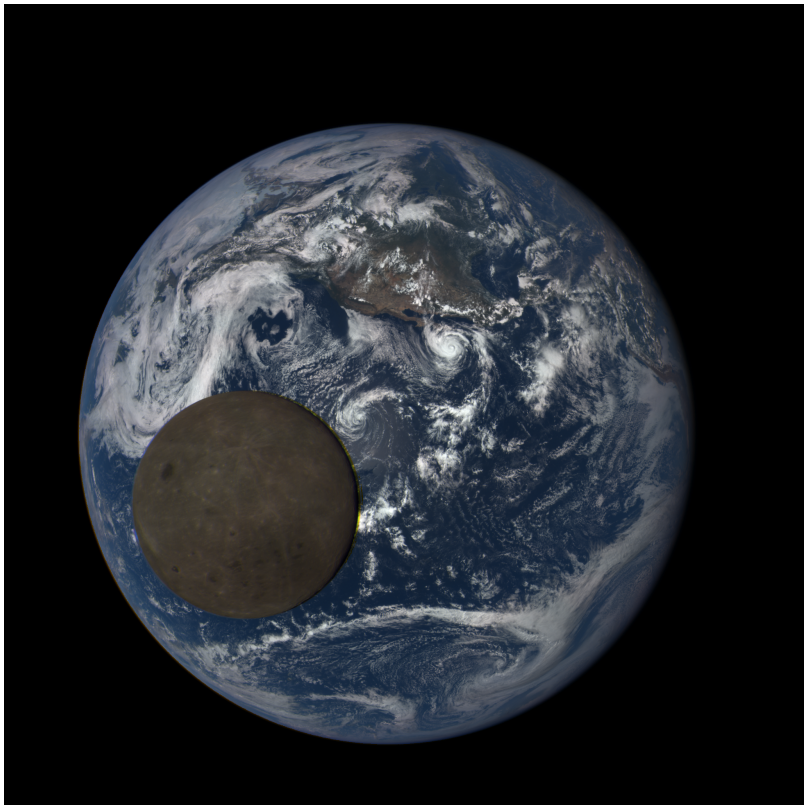
1: NASA GSFC, 2: UMBC JCET, 3: Morgan State Univ., 4: USRA

Aerosols are sometimes near clouds

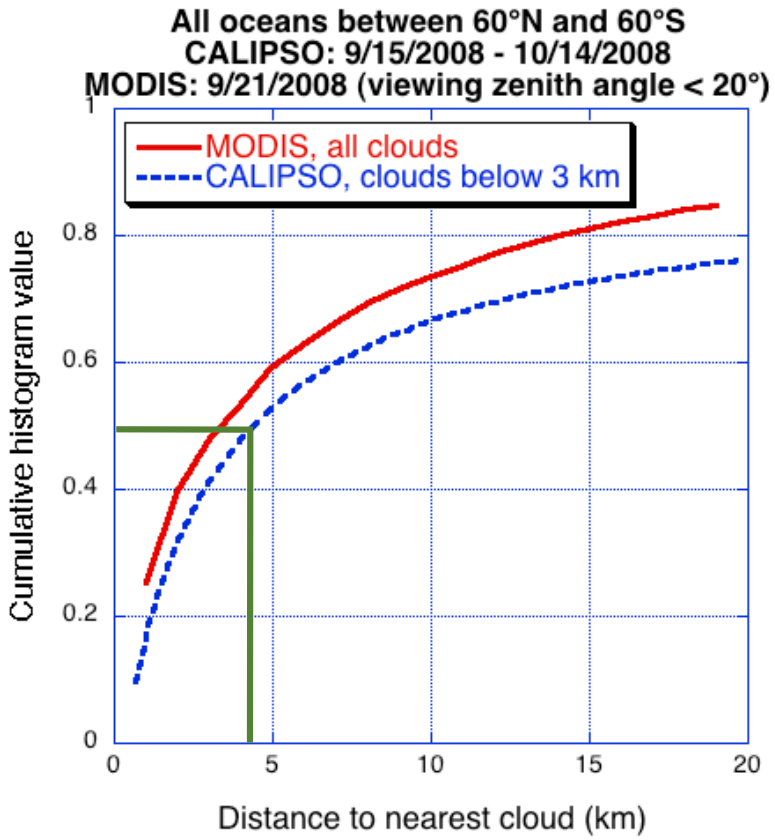
Arctic haze

Saharan dust & clouds

Most clear areas are not too far from clouds



DSCOVR spacecraft, EPIC imager, July 16, 2015



Aerosols are different near clouds

"… aerosol measured in the vicinity of clouds is significantly different than it would be were the cloud field, and its proximate cause (high humidity), not present".

"… ascribing changes in cloud properties to changes in the aerosol remains a fundamental challenge."

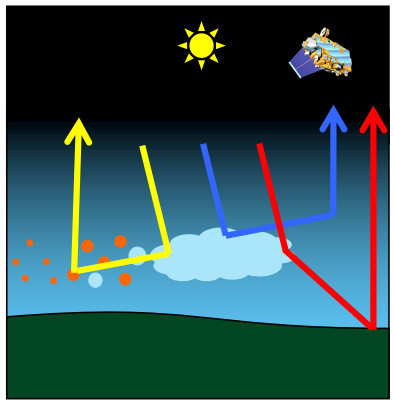
IPCC AR5, Chapter 7

Aerosols are different near clouds due to:

- Aerosol swelling
- Cloud processing of aerosols
- New particle formation

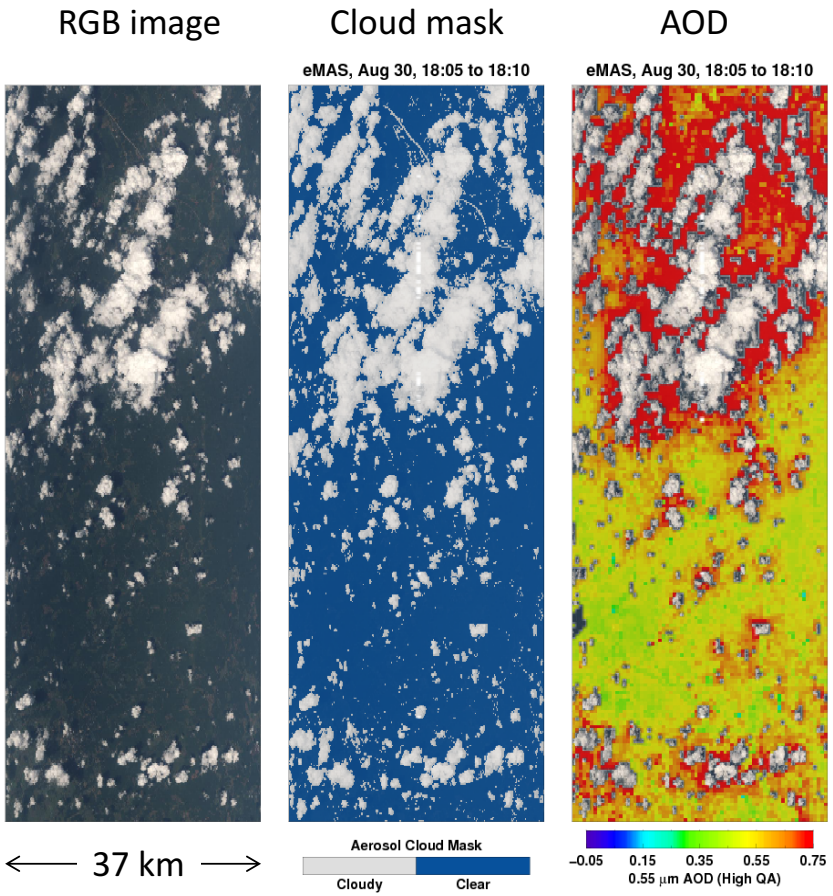
Remote sensing issues can exaggerate the differences:

- Undetected cloud droplets
- 3D cloud scattering
- Instrument blurring

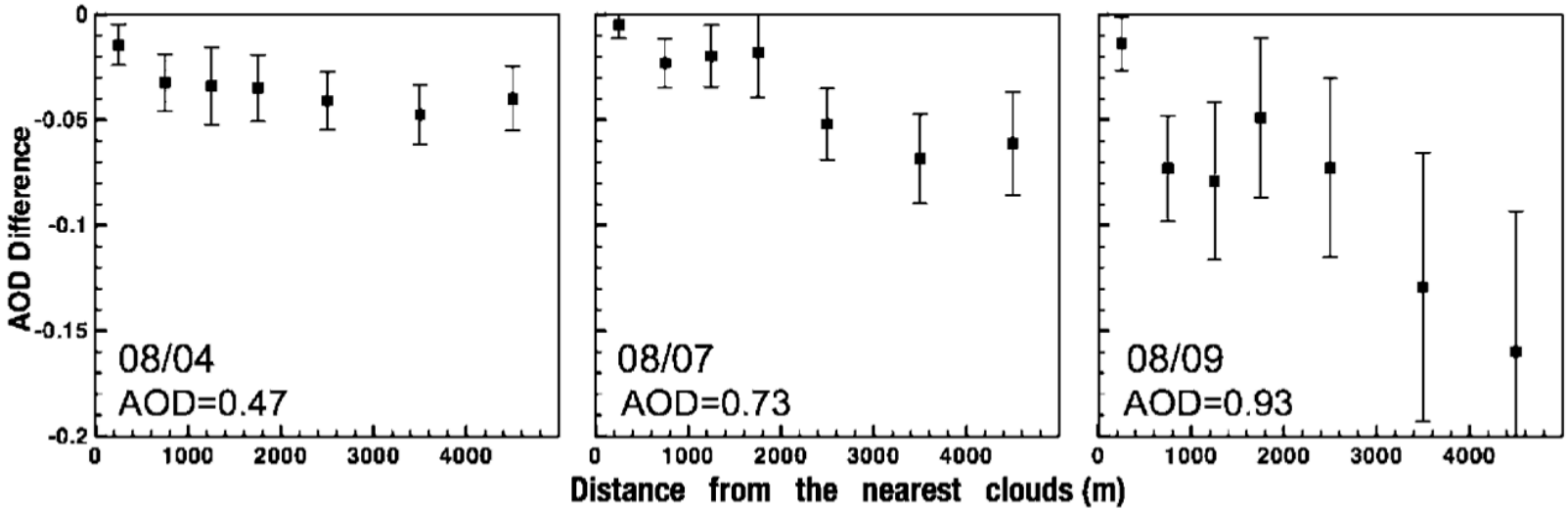


Airborne data shows near-cloud enhancements

NASA ER-2 eMAS
Centreville, Alabama, August 30, 2013



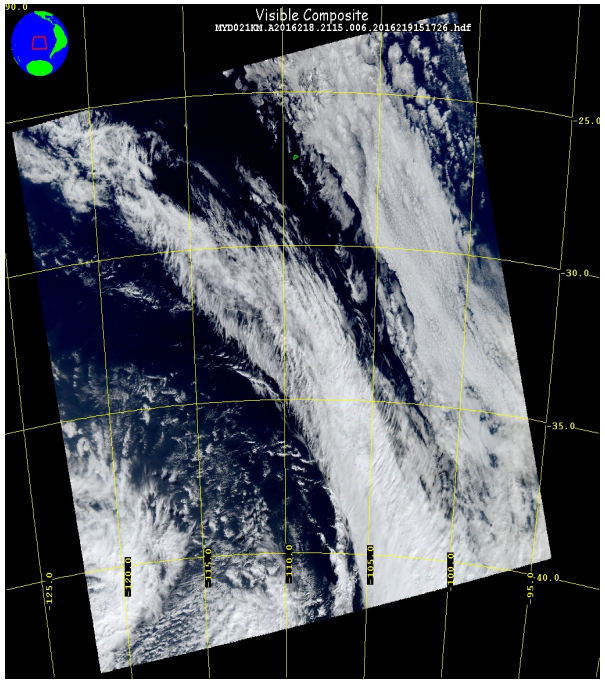
Airborne HSRL: near-cloud enhancements vary



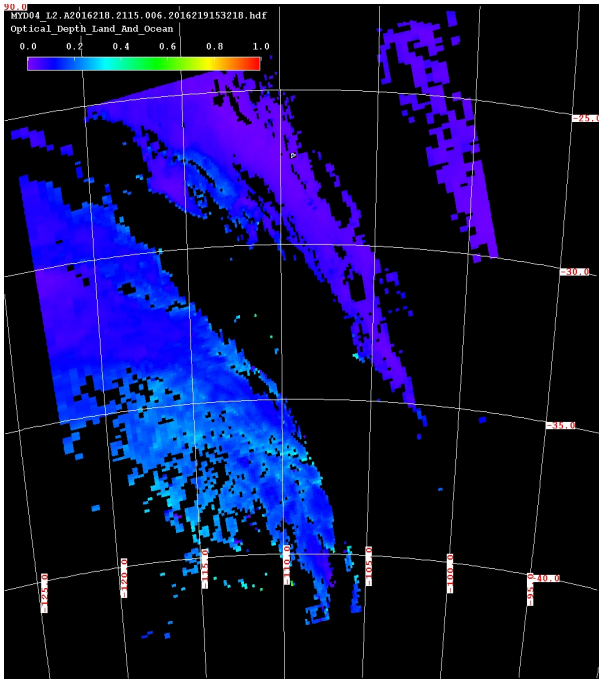
Su et al. (2008)

Satellite images also show near-cloud enhancement

MODIS image

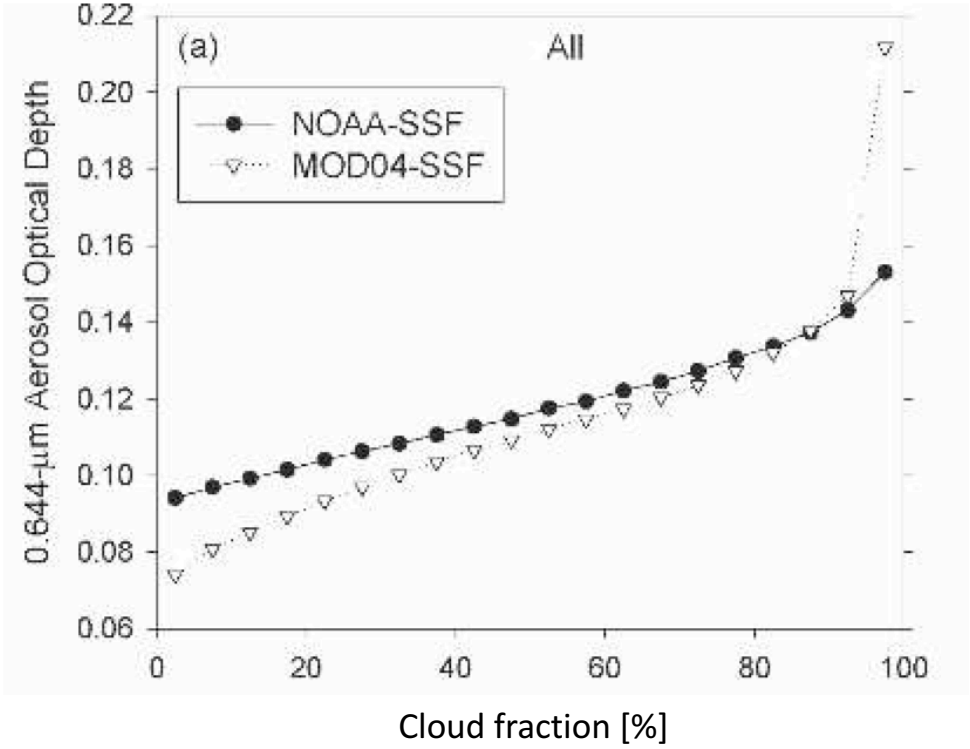


AOD

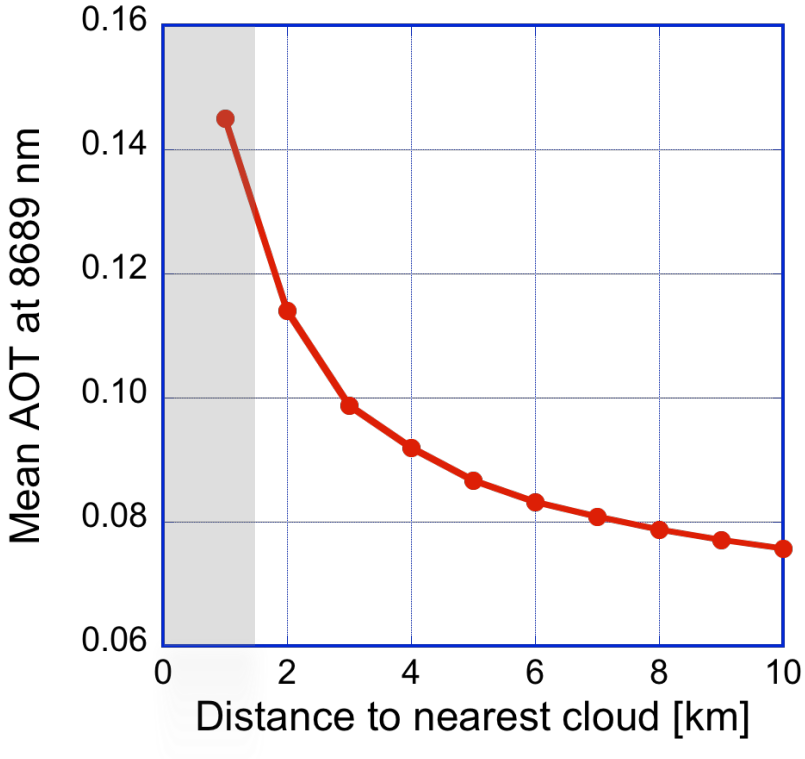


Aqua MODIS, August 5, 2016

Cloud-related enhancements are statistically large



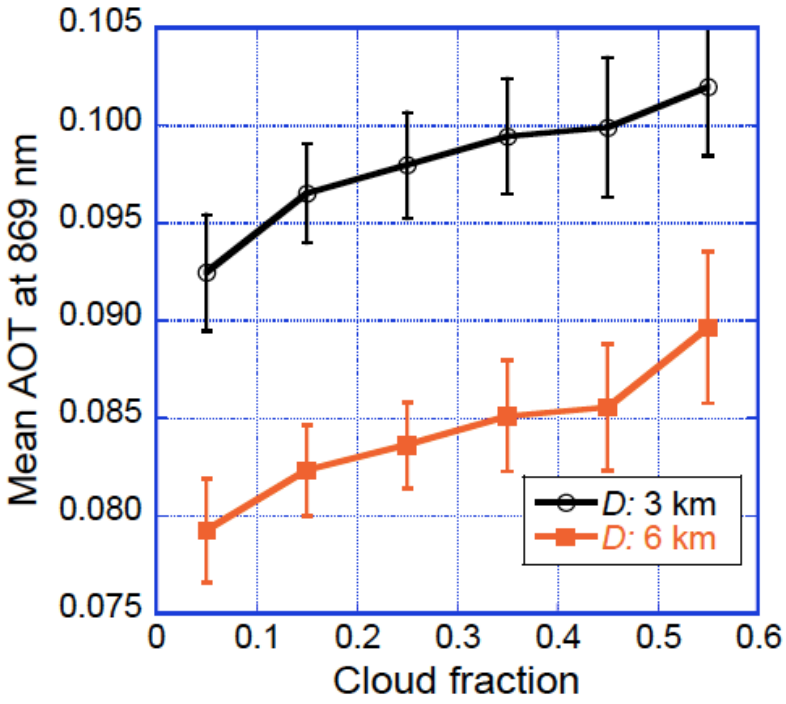
Loeb and Manalo-Smith (J. Clim., 2005)



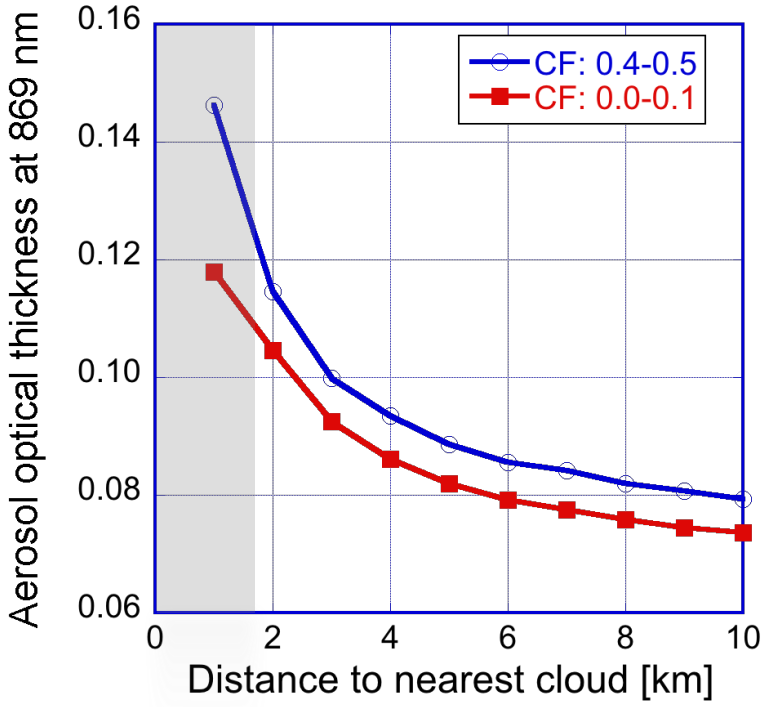
Based on Várnai and Marshak (Rem. Sens. 2015)

CF & distance to cloud impact AOD separately

Constant distance to cloud (*D*)



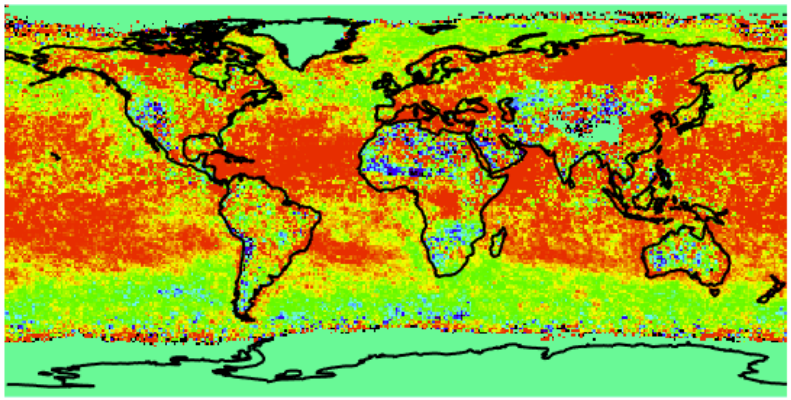
Constant cloud fraction (CF)



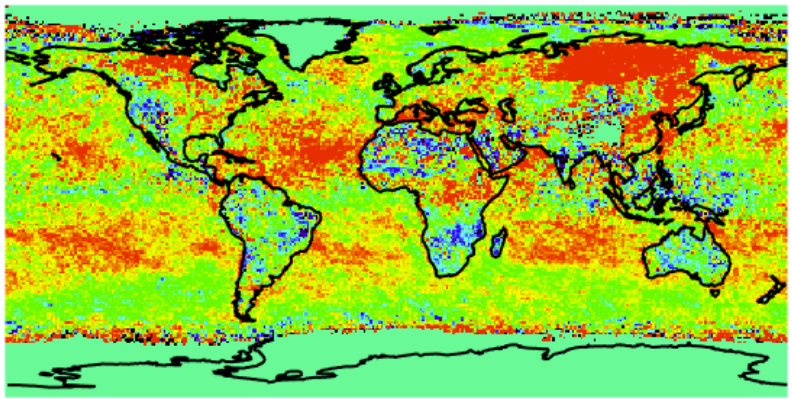
Várnai and Marshak (Rem. Sens., 2015)

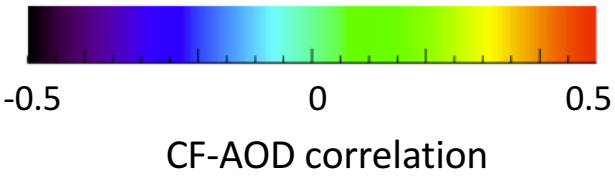
CF-AOD correlation is positive throughout the globe

MODIS



MERRA-2

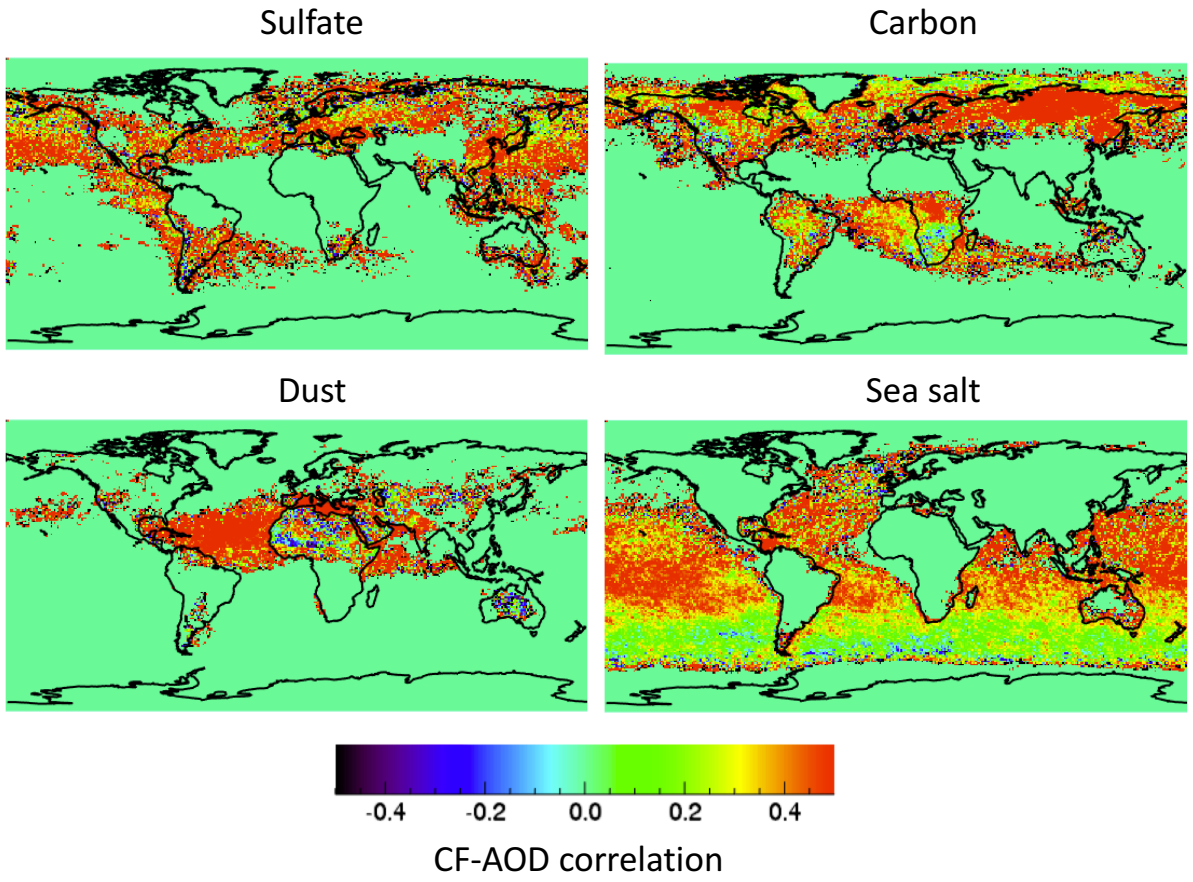




June-July-August, 2012-2014

Similar behavior for other models (e.g.,Quaas et al., ACP, 2010)

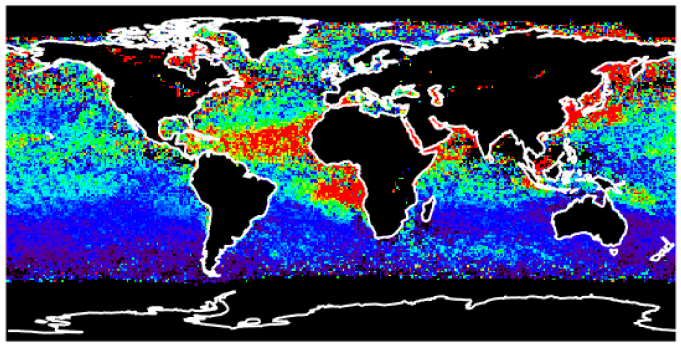
MODIS CF & AOD well-correlated for all MERRA-2 aerosol types



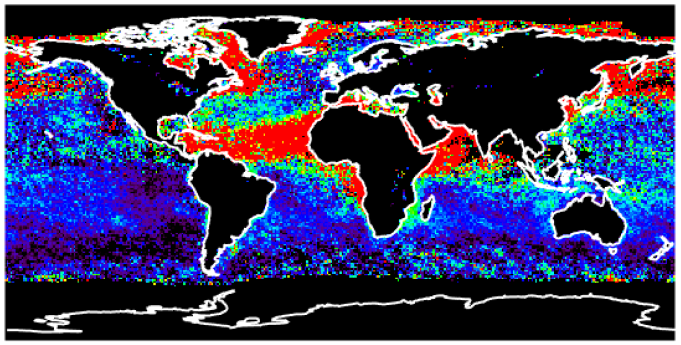
MODIS Aqua, JJA 2012-2014

AOD often increases with CF more for small mode

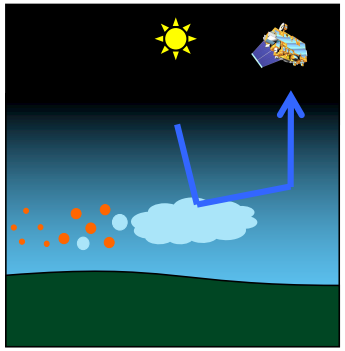
Small mode

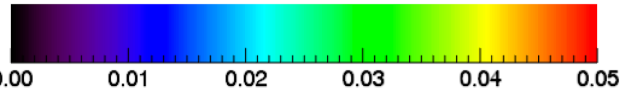


Coarse mode



3D “bluing” effect



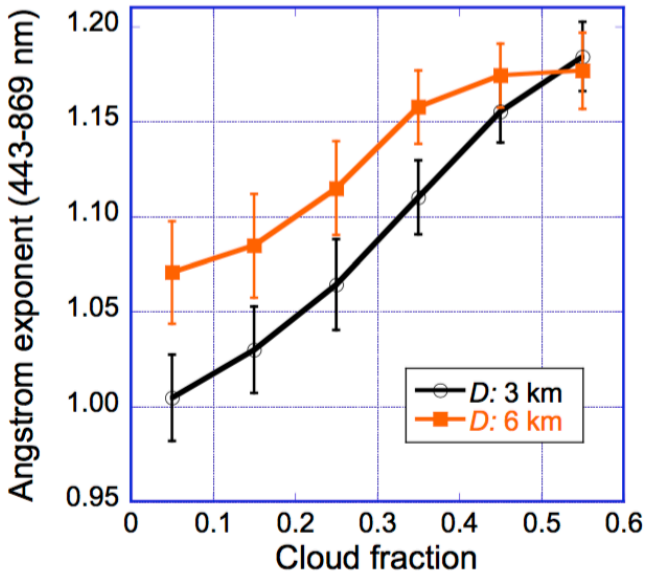


AOD(days with high CF) – AOD(days with low CF)

- small mode is more hygroscopic
- coarse mode aerosol is at altitudes with dry air
- cloud processing creates small aerosols
- 3D effect: bluing

MODIS Aqua, JJA 2012-2014

AE decreases near clouds even if it increases with CF

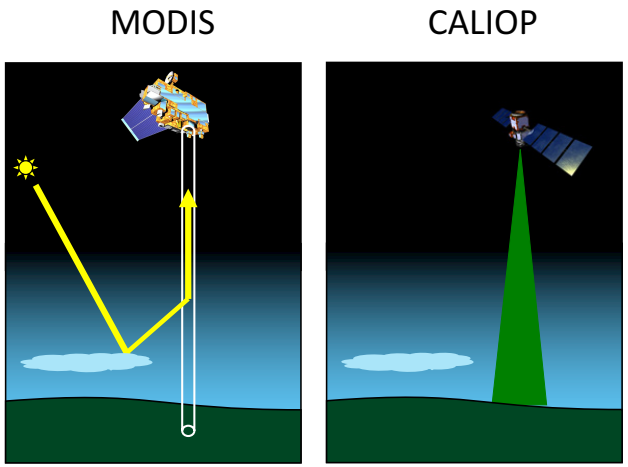


CF: changes in large-scale environment

D: effect of individual clouds

Várnai and Marshak (2015)

3D causes significant part of near-cloud enhancements

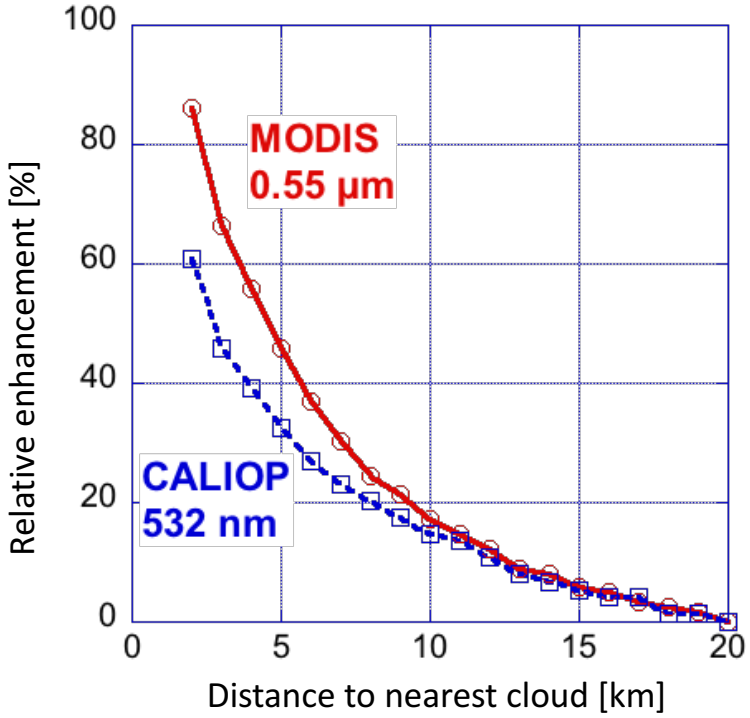


CALIOP can observe enhancements from:

- Aerosol swelling
- Cloud contamination
- Cloud processing

It is not affected by:

- 3D enhancement
- Instrument blurring



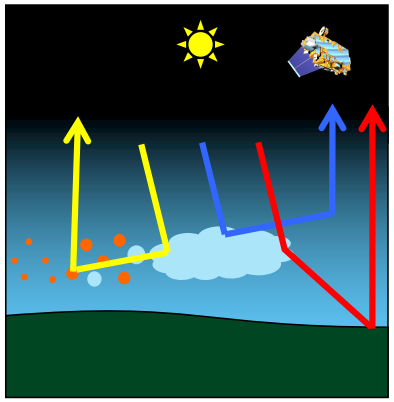
Global oceans, 60°N – 60°S (Várnai et al., ACP, 2013)

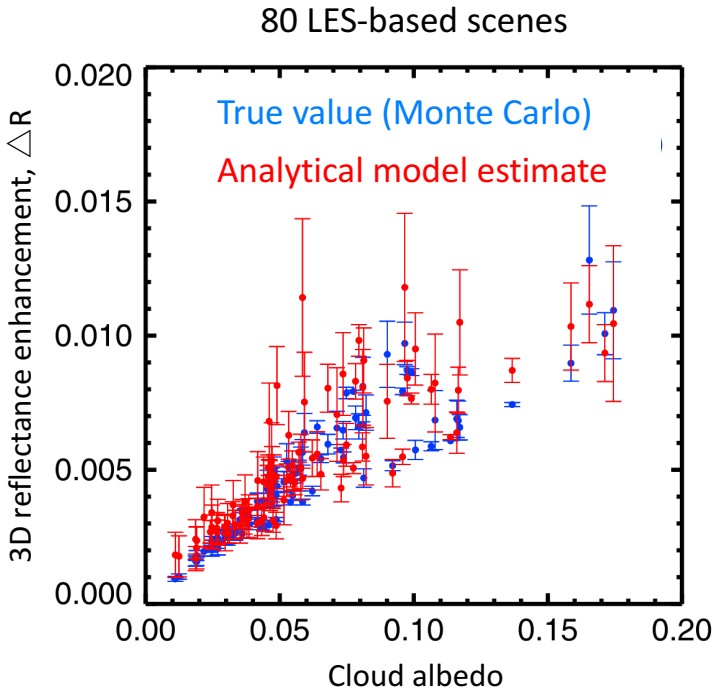
Analytical model is tested for removing 3D enhancements

$R_{1D} = R_{MODIS} - \Delta R$

ΔR is function of:

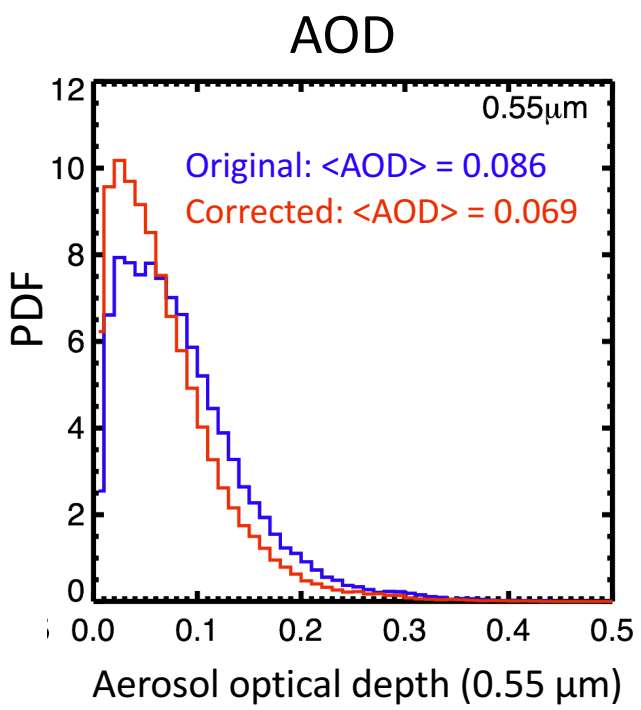
- sun-view geometry
- mean cloud altitude and albedo
- surface albedo
- aerosol parameters

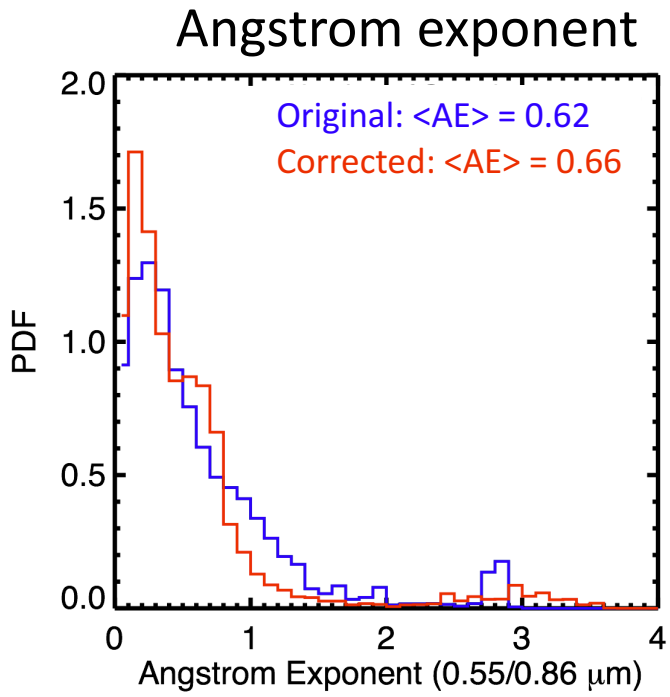


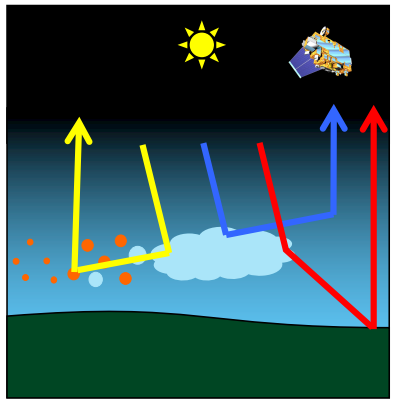


Wen et al. (JGR, 2016)

3D correction reduces retrieved AOD-s and can change Angstrom exponents either way







31 MODIS granules off the West coast of North & South America, August 1-8, 2013

Summary

- Cloud fraction and AOD are positively correlated through most the globe and for all aerosol types. Correlation is stronger for MODIS than MERRA-2.
- In many areas, aerosol size distributions shift toward smaller sizes as CF increases, but it always shifts toward larger size near clouds.
- 3D radiative effects have a significant impact on satellite radiances near clouds, where a large portion of clear-sky columns occur.
- An analytical model is being developed to help dark target aerosol retrievals by estimating 3D reflectance enhancements.

Impact of 3D effect varies with retrieval algorithm

3D effects vary with

- Wavelength (deep blue vs. dark target)
- Polarization (POLDER vs. MODIS)
- View directions (MISR vs. MODIS)

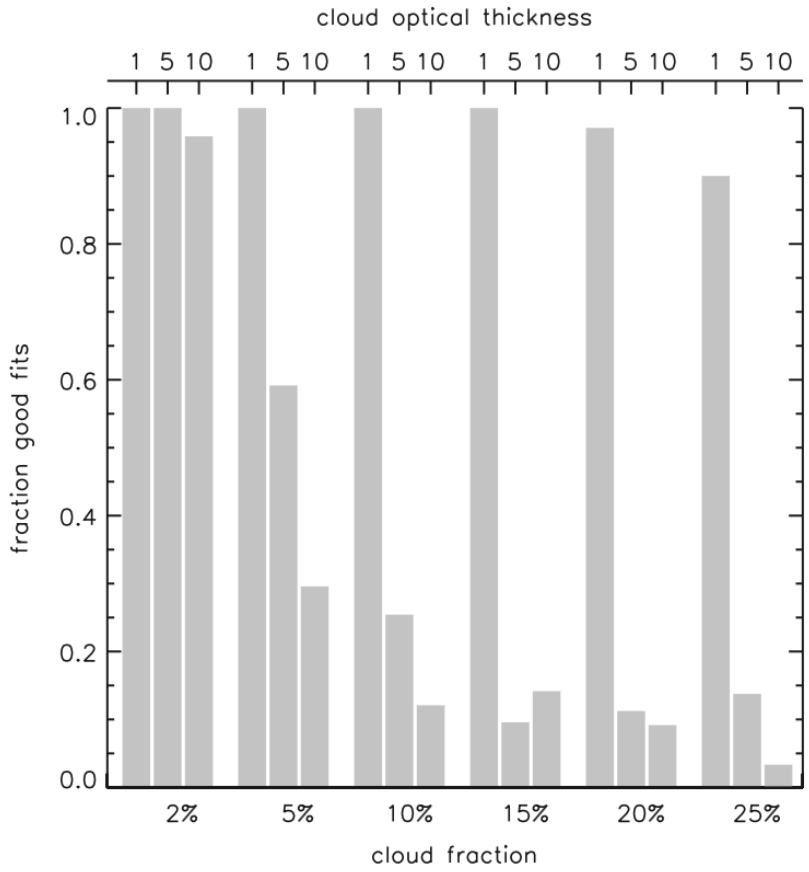
POLDER: 3D effects do not cause problems if

CF < 5% or $\tau_{cloud} < 5$

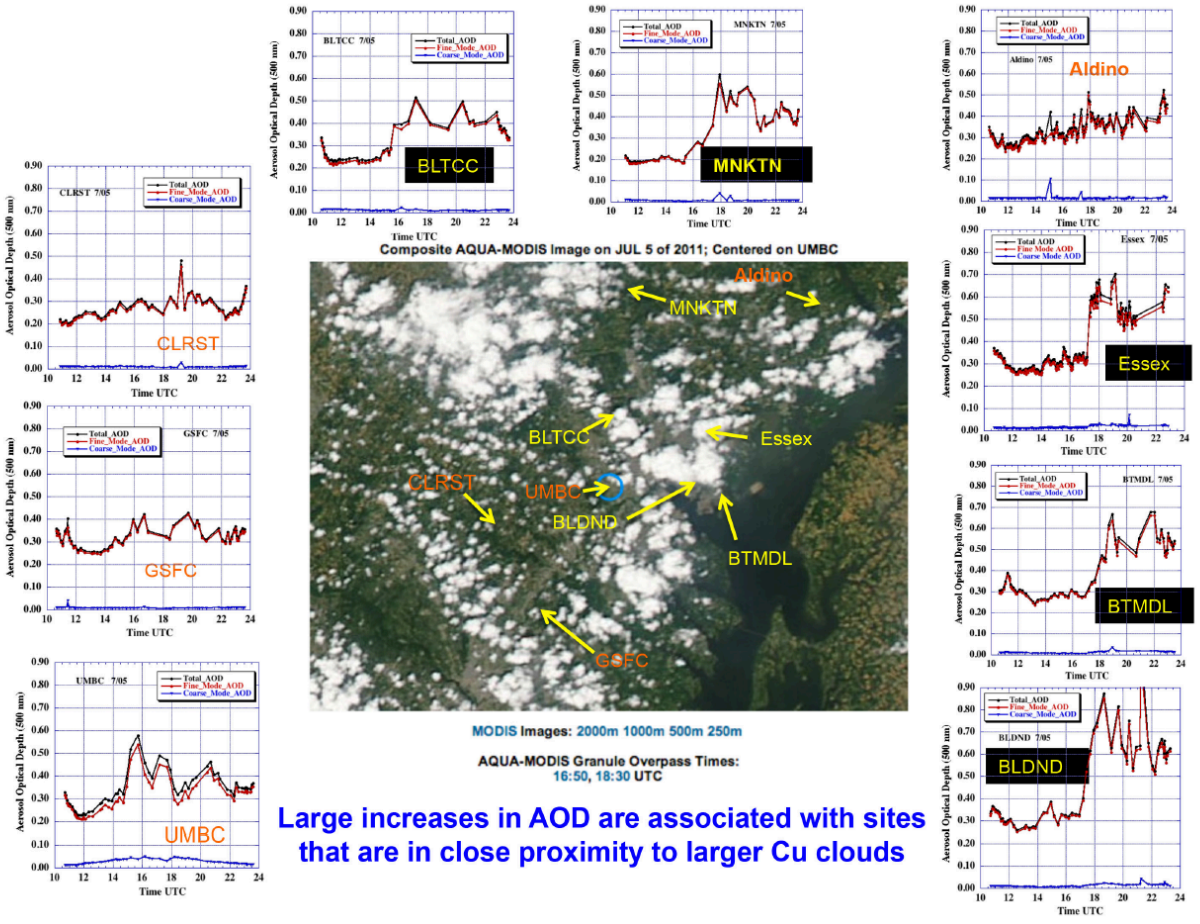
For CF = 25% and $\tau_{cloud} = 10$:

ΔAOD = 0.12 (≈25%), ΔSSA = 0.09

Stap et al. (JQSRT, 2016):

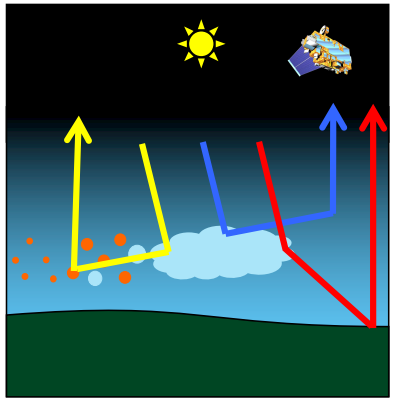


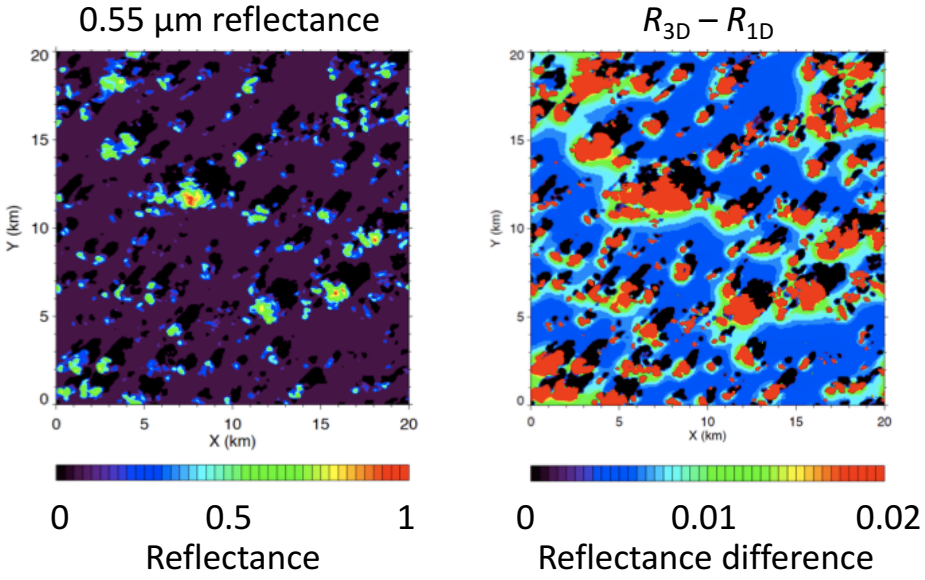
Aeronet: small mode increases near clouds



Eck et al. (2014)

Simulations: 3D enhances radiances around clouds





Radiance enhancements → higher retrieved AOD values